

# Designing the First Satellite Built in Australia

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## Introduction

Three boys, two continents and a spot of light. Little did Richard, Jan and Owen know how that spot of light moving slowly cross the sky would determine their lives.

The spot of light was, of course, the first artificial earth satellite, Sputnik 1, launched by the Soviet Union in October 1957. Among other things, it lit up the imagination of those boys who became space nuts soaking up every bit of information about satellites, space, rockets and astronomy. Not that there was much serious information as this was the height of the competition between the Soviet Union and the USA – the Cold War.

Less than a decade later Richard and Owen met when they joined the Melbourne University Astronautical Society. With other members, the squeaks and whistles of many satellites, including one bound for the moon, were received on our home made quad helix antenna and an ex-war time receiver. We supplied weather pictures from TIROS satellites to the Bureau of Meteorology (Australia's approximate equivalent of the National Oceanographic and Atmospheric Administration, NOAA) for some 18 months before it got its own equipment. I still remember being told that pictures of clouds from space would never help weather forecasting!

Then one day - both Richard and Owen claim responsibility – the idea of building our own satellite was suggested. Since there was no one in Australia who had built a satellite, there was no one to tell us that it was not possible.

So we did.



## Preparations

The first task was the most important – what was our satellite to be called? After much discussion we settled on *Australis*, signifying our huge, southern country.

Next, who would launch Australis? There were no launch sites nor launch rockets in Australia, so our thoughts turned overseas. The baddy, the Soviet Union, was out of the question but our side, the United States, had already launched three amateur radio satellites, so there was our possible launch. To confirm that we could get a launch, a letter was air mailed to Project OSCAR on the West Coast, would they launch our satellite? A reply came back, very promptly, they would *try* to launch our satellite. That was good enough for us.

Now, what are we going to build?

## The Mission

First, Project OSCAR suggested a satellite size of around the dimensions of their forthcoming OSCAR 4 satellite, approximately 50 x 30 x 20 cm (22 x 12 x 8 inches).

We quickly realised that, for a number of good reasons, an amateur radio satellite was the ideal goal. Not only were the three previous OSCAR satellites built by and for amateurs, it also solved the question of what radio frequency we would use. The two metre amateur band, as OSCAR had used. There was another advantage, too. There was no need for approval by the Australian spectrum management people as our satellite would be a mobile station of one of our members! Regulators off our back.

Now the question was, what do we want our satellite to *do*? (Just the sort of question a bunch a nerdy, somewhat asberger-syndrome affected boys would ask.) The answer was obvious – a two metre to two metre linear translator. Quickly, those who understood these things – Richard was a law student and Owen in the first year of his electronics degree – realised that this would be very difficult. The issue, of course, was filtering sufficiently so that the transmissions would not de-sensitise the receiver to such an extent that it would be incapable of receiving anything. The only reasonable solution in those days was a cavity resonator and a good one at that. Half a wavelength at two metres is one metre, which is much bigger than the agreed size for Australis. We also realised that changes in size due to temperature changes in space might seriously compromise the performance of the resonator. And we had no idea what those temperatures might be – recall that no one in Australia had any experience with satellites then.

A channelised frequency modulated signal might be an alternative but it would also require very effective filtering.

Finally, it was decided that we would focus on a fundamental issue for satellite communications, namely orienting the antennas to optimise signals. We also decided that we would investigate longer range communications with a ten metre transmission. So there was our mission definition – simple satellite, but not so simple for us.

## Orientation and Stabilisation System

Any satellite transmitting or receiving radio signals should have a reasonably steady signal at the receiver to avoid “fades” where data is lost or compromised. This is as true today as it was in Australis’ time.

We had no idea what the rate of rotation of Australis might be. Launch rockets typically rotate about their longitudinal axis to help stabilise the direction that they are pointed. Also, when Australis was ejected from the launch rocket, any imbalance in the ejection springs would add a further rotation, about a different axis. We had to live with the notion that Australis would be spinning when placed in orbit at a rate of perhaps a rotation every few seconds. It scarcely needs saying that this uncertainty made the design of a stabilisation system and prediction of its performance difficult at best. Furthermore, at the time we had only a vague understanding of the likely mechanical properties of the satellite.

We understood that large satellites were stabilised and oriented in three directions using a complex set of sensors, reaction wheels and gas jets. This was out of the question for Australis, if for no other reason than we simply could not afford the electrical power necessary to run such a system. No, the stabilisation system had to consume minimal electrical power, or ideally none. Fortunately, Owen and

his colleague, Steve, who had been press-ganged into the Australis project, were electrical engineering students and had recently learned some of the physics of magnetism and magnetic hysteresis. Equally fortunately for Australis (and indeed for all of us earthlings) the Earth has a magnetic field and this afforded us a means of crudely stabilising and orienting the satellite.

There are, therefore, two parts to the subsystem – a means of reducing any residual spin of our satellite as it enters orbit and a means of orienting it in a direction suitable for the antennas. The sub-system was called the Magnetic Attitude Stabilisation System, MASS, consisting of orientation and stabilisation components.

## Stabilisation Component

When magnetic materials are subject to changing magnetic fields, energy is absorbed by the material as the atoms (or rather the magnetic fields of the atoms) within the material are re-oriented by changes in the magnetic field. In some materials, used for electrical transformers for example, this energy is small but in others much larger. Could a material with a sufficiently large “hysteresis loop”, as it is known technically, absorb the rotational energy of Australis? The size of the hysteresis loop is a measure of the energy absorbed by the magnetic material for each reversal of the magnetic field, so a large hysteresis loop, absorbing a relatively large amount of energy, is desirable for this task.

After consulting some technical books in the University’s library, Steve reckoned that it might just be possible to reduce any satellite spin to a reasonable value in a few weeks. Any spinning or rotating could never be totally eliminated because, as the speed of the spinning was reduced, so the number of magnetic field reversals, and the rate of absorbing rotational energy drops. Nevertheless, reducing the rate to, say, one rotation or fade per minute would make communication far more feasible.

Eddy currents in Australis’ aluminium skin due to the changing Earth's magnetic field as the satellite rotated would also absorb energy and contribute to reducing the spin. We were unable to calculate the likely contribution of this mechanism.

We found an alloy consisting of about 50 per cent iron and 50 per cent nickel with a very high hysteresis loop. We could buy it at a cost of US\$35 plus costs for the freight and customs clearance. This was one of the few parts of Australis that were not donated and we had to buy!

There was one further problem, however. The material had to be annealed in a dry hydrogen atmosphere at 2150°F for 2-4 hours, followed by a furnace cool at 100-200°F per hour down to 800°F to achieve the desirable properties. Finding someone willing to heat hydrogen to high temperatures would be a challenge! Nevertheless, that brave someone was found at Monash University in Melbourne and the wires were duly soaked in a hot hydrogen atmosphere for the due time and allowed to cool at the due rate. The challenges of building a satellite! (Recently Fate in the form of rabbits brought together Owen and the student who built that furnace!)

Following the annealing, there was a memorable afternoon as Steve and I set off to the student’s electronics laboratory in the Engineering Faculty at Melbourne University to make the measurement of the hysteresis loop. Arriving at the laboratory with the material in the form of wires about 3mm diameter, an irate and insistent lecturer demanded that I not enter wearing flip flops – imagine the danger present when measuring a magnetic hysteresis loop when wearing thongs! (The voltages were low.) Nevertheless, the rules were the rules and I trudged off to change into something more to his liking, and in accordance with the rules. Eventually, the hysteresis loop was displayed on an

oscilloscope and the numbers recorded and analysed. This is not a difficult measurement to make (I've done it a few times since) but it was a novelty then, and a satisfying one, when done for the first time.

The upshot was that, yes, with a handful of these wires, the likely spin of the imagined Australis could be reduced to a reasonable value in a reasonable time. With all the unknowns, any quantitative analysis and estimate of the spin-down time was guesswork, but it did work.

After all this challenging and very interesting experience, we had our stabilisation system – a bundle of innocuous wires. Better than any lecture or practical class at University, we learned and thoroughly understood the principles of magnetic materials and hysteresis loops.

Significantly and most importantly, the wires required no electrical power for them to do their job; they were passive.

The ideal orientation system would orient Australis in a fixed direction relative to the Earth, so that the various antennas could be arranged to maximise signals towards the Earth. As we've seen, an active orientation system was utterly impractical for us. We needed another passive system and, once again, the Earth's magnetic field offered the solution.

As any child knows, two magnets attract and align themselves. The Earth's field is one of those magnets, so all we had to do was to place a magnet in Australis and, hey presto, Australis would be aligned with the Earth's magnetic field. Since the Earth's field is very roughly parallel with the Earth's surface over much of the populated regions (but not at the poles), here was an easy solution.

Not quite so quickly. How big a magnet is required to follow the earth's magnetic field, especially given that the field dips down at the Earth's poles and a satellite tends to do a 180 degree tumble as it passes over each pole? Furthermore, we had introduced a permanent magnetic field which may affect the hysteresis of the stabilisation wires. These were serious considerations that had to be understood and dealt with. More delving into technical books dealing with magnetic fields and, in fact, much of the theory is contained in Physics and Mathematics that was well beyond our understanding at that stage of our University careers – vector calculus and the like. Nevertheless, Steve was able to convince himself that magnetic orientation was feasible.

A loud speaker company in Melbourne that manufactured audio loud speakers supplied us with magnets.

We called our system the Magnetic Attitude Stabilisation System (MASS).

The two metre antennas were mounted parallel to the axis of the magnet and within a few weeks Australis OSCAR 5, as it is known in orbit, had locked on to the earth's magnetic field and the 2 m signal was steady. Success. And the first time such a system had been used on an amateur satellite.

## Radio Transmitters

There seemed to be little value to fly MASS without measuring its performance, so that dictated a telemetry system and we decided that a simple eight channel telemetry would suffice. The measurement channels were:

- 1: HI identification
- 2: Battery current drain
- 3: X axis horizon sensor
- 4: Battery voltage

- 5: Y axis horizon sensor
- 6: Internal temperature
- 7: Z axis horizon sensor
- 8: Skin temperature.

All channels measured the parameters by the frequency of an audio tone, while the distinctive HI in Morse code identified channel 1. Each channel was sampled for 6.5 seconds within a 52-second telemetry cycle. The audio frequencies ranged from 400 Hz to about 3 kHz.

The three horizon sensors were buried in tubes to restrict their view and shade them from extraneous light. This led to a concern for the potential for damage and destruction should a sensor see sunlight directly. A balance had to be struck between a reasonable field of view for the horizon sensors and a narrow field to reduce the risk of damage from the sun. This was a risk that we had to accept but no damage occurred during the flight.

Each of the two radio transmitters, one two metre the other ten metre, carried this telemetry.

But we foresaw a problem. Path loss considerations demanded that the ten metre transmitter be considerably higher power than the two metre transmitter; nominally 250 mW versus 50 mW. The ten metre transmitter would seriously reduce the lifetime of the battery powered satellite, so we decided that we would fly a command system so we could turn the ten metre transmitter on and off to conserve battery energy. That was yet another first for an amateur radio satellite but being first didn't concern us – if we even knew then.

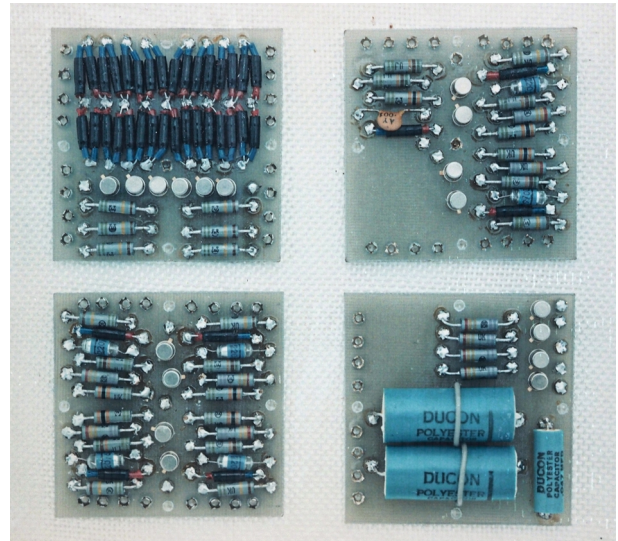
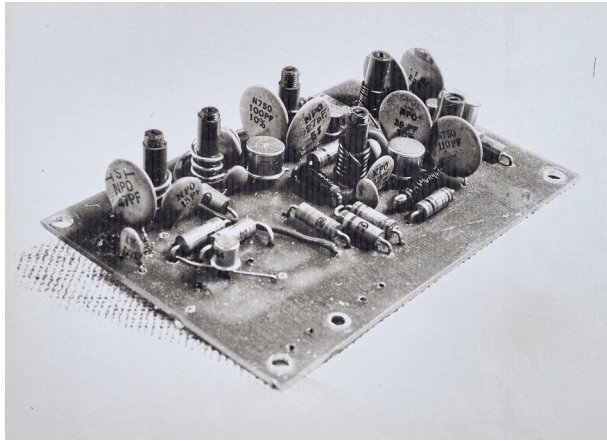
So now we had the system design for our Australis satellite, the components of which were:

1. Stabilisation system to reduce any residual tumbling in orbit.
2. Orientation system to ensure that Australis' antennas are in a direction favourable for receiving the signals on the ground with no, or minimal fading.
3. Two-metre, 50 mW transmitter, amplitude modulated by the telemetry signal.
4. Ten-metre, 250 mW transmitter, also amplitude modulated by the telemetry signal.
5. Command system consisting of a receiver and decoder to turn the ten-metre transmitter on and off.
6. Antennas for the two transmitters and the command receiver.
7. "HI keyer" to generate HI in Morse Code.
8. Telemetry system to generate the modulation signal for the two transmitters.
9. Battery to power the electronics.
10. Separation system to eject Australis from the launch rocket, including a master on/off switch
11. Mechanical structure, including thermal control which was outside our control and it was finally designed by NASA.

Without amateurs listening to Australis and reporting the signals they received, the project was worthless, except perhaps as an ego trip for us students. Accordingly, a ground segment was recognised as consisting of:

12. A means of generating and distributing predictions for when and where to look for Australis.
13. Network of amateurs to receive and report the signals they heard.
14. Analysis centre to analyse reception reports from receiving stations.
15. Command stations to send command signals to control the HF transmitter

Although we did not express the design decisions in this way, this was a system design that clearly delineated Australis' components, functions and interfaces, even if it was not formally documented except perhaps in the User Manual published before the launch. Here are some of the electronics:



*On the left is the 2 metre, VHF transmitter being constructed and on the right the HI keyer boards*

## Testing

Of course we wanted to be sure that Australis had a chance of working once in orbit, so we needed to test the components and then the satellite as a whole in conditions that at least approximated those it would face in space. However, there were no available test chambers – no one had built a satellite in Australia before - so we had to improvise.

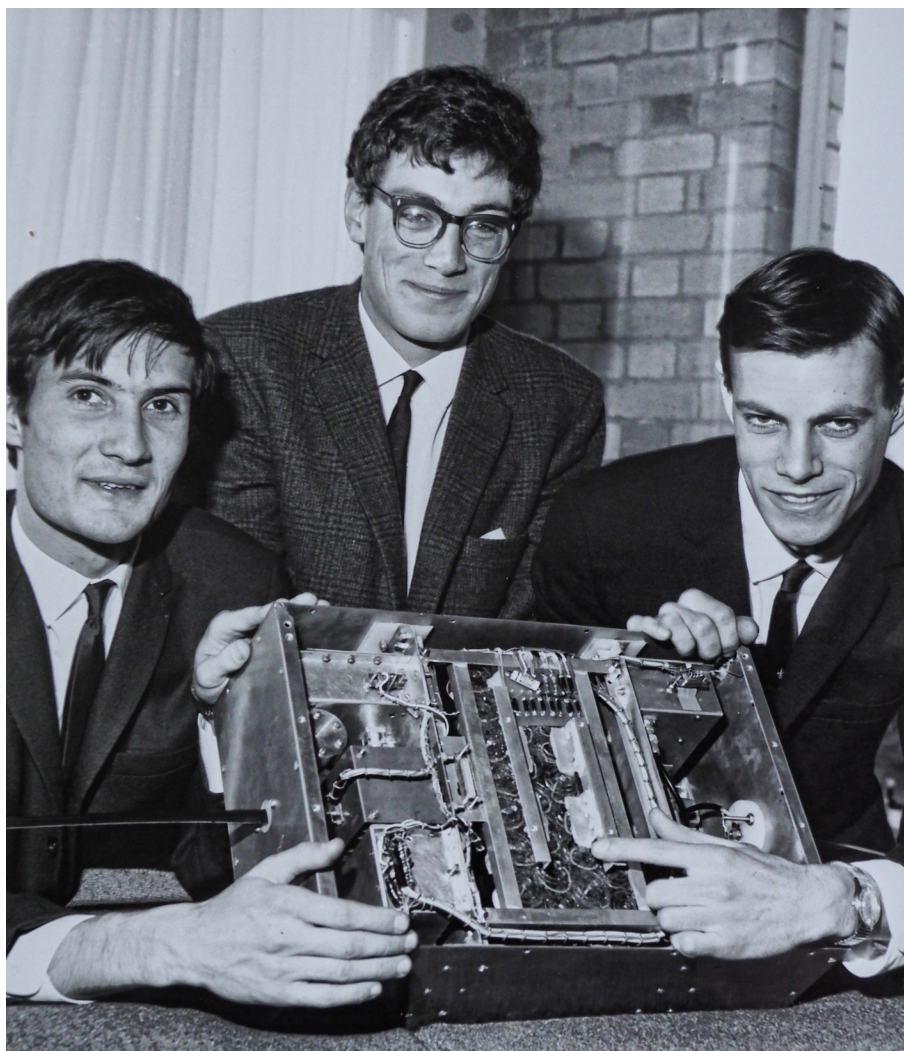
Richard worked part time for the Bureau of Meteorology and had access to weather balloons. What fun we had testing our sub-systems by flying them on weather balloons from the University – until, that is, the civil aviation authority suggested we should take our balloons well away from Melbourne's then international airport. Vacuum tests completed.

High temperature tests were conducted in Richard's home oven while his future wife objected that she was unable to cook dinner with that metal box in the oven. A large chest freezer in the Glaciology Department of the University was co-opted without the professor's knowledge, of course, for low temperature tests. Antennas tuned.

All good and ready for shipment.

This is how Australis looked before being shipped to California:





*Owen, Richard and Paul with the completed Australis satellite in May 1967 before it was shipped to California. Batteries in the centre with electronics boxes either side. Antennas are flexible steel tape rulers. The magnet is not visible and the hysteresis rods are glued to the top cover.*

## **Launch and Flight**

Three of the team delivered Australis to Lance Ginner of Project OSCAR in San Francisco – Lance is here at the Symposium. Unfortunately, the US Air Force - understandably - decided that it could not launch an amateur satellite built by a bunch of mostly undergraduate students from a foreign (if friendly) country, so Australis lay in its delivery box in Lance's garage for nearly two years.

Then came the news that AMSAT had been formed and would fly our satellite! The third boy who saw that moving spot in the sky, Jan King, was put in charge of preparing Australis for flight. Jan and the first AMSAT president, Perry Klein, are both at this Symposium. Thanks Jan and thanks Perry, with whom Richard and I will have an eyeball QSO for the first time.

And fly Australis OSCAR 5, as it is known in orbit, we did. Can you imagine the excitement when we first heard our baby squeaking and beeping on 23<sup>rd</sup> January 1970? I still tear up when I hear the sounds of a very successful Australis OSCAR 5 in orbit.

Two audio files of the telemetry are included in the Symposium papers. Have a listen.

For a detailed report on the flight, see Jan King's article in the December 1970 edition of the QST magazine and the 9 February 1970 edition of Goddard News.

The firsts we achieved with AO5 were:

- First Australian-built satellite.
- First non-US amateur satellite.
- First University satellite.
- First non-government secondary payload launched by NASA.
- First amateur radio satellite launched by NASA.
- First satellite, along with Tiros M, to be launched by the then-new Delta N rocket.
- First 10-metre HF transmitter flown on an amateur satellite.
- First telemetry system flown on an amateur satellite.
- First command system flown on an amateur satellite. Commanding took some time to achieve thus shortening the life somewhat to about four weeks.
- First "PMASS" magnetic stabilisation and orientation system to stabilise and orient a satellite. There have been about 40 subsequent systems flown.
- First use of "Standard Orbits" method for predicting passes and for tracking. We understand that the method was later adopted and improved by NASA for use by US Antarctic expeditions.
- First time that satellite predictions (in this case equator crossings) had been transmitted directly from a computer to users via radio without human intervention.

There is a suggestion that Australis OSCAR 5 was among the early pioneers of small satellites launched from Vandenberg Air Force Base in California.

In addition, AO5 trained two groups, the Australians and the US AMSAT.

At the 23 July 2011 reunion of the group, the contribution of one of our group, Peter, to AMSAT with his command receivers was acknowledged: the AMSAT 7 command system continues to operate, along with the RTTY telemetry, after some 40 years since launch, and it is the longest surviving space command system ever. (He was advised not to use CMOS logic for his system as it was believed it would not survive.)

It was to be over eleven years before the Surrey University group under Professor Martin Sweeting flew the first of their small and relatively inexpensive satellites.

As it turned out, we were pioneers but not intentionally so. We were simply following our interests.

For more details, visit [www.australis-oscar5.weebly.com](http://www.australis-oscar5.weebly.com) where the Australis OSCAR 5 book can be bought.